Technical Report

R 458

PROTECTION OF MOORING BUOYS PART VIII. RESULTS OF SEVENTH RATING INSPECTION

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NAVAL FACILITIES ENGINEERING COMMAND

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PROTECTION OF MOORING BUOYS — PART VIII. RESULTS OF SEVENTH RATING INSPECTION

Technical Report R-458

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by

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ABSTRACT

This is the eighth of a series of reports on the protection of mooring buoys. Thirteen test buoys were given their seventh rating for extent of coating deterioration, corrosion of steel, and fouling. Two other buoys had previously been removed from testing because of advanced deterioration. The coating systems on three of the buoys were in good condition while those on 10 others showed varying degrees of moderate deterioration. Two sets of 13 panels each, coated with the different systems used on the buoys, were given their sixth rating inspection after 3 years of exposure. One set was exposed in San Diego Bay and the other in Port Hueneme Harbor. The condition of the coatings on both sets of panels was generally better than that of the buoy coatings, but there was a general correlation between the conditions of the two test groups. On buoys coated with antifouling paints, no detectable antifouling protection remained after 25 months, but on both sets of test panels, two antifouling paints were still appreciably reducing fouling after 3 years.

Three of the buoys were cathodically protected with zinc anodes. The level of protection was high enough to mitigate rusting in the underwater portions of these buoys.

The Laboratory invites comment on this report, particularly on the results obtained by those who have applied the information.

CONTENTS

INTRODUCTION

The presently specified coatings for mooring buoys have performed unsatisfactorily; consequently, the Bureau of Yards and Docks assigned the Naval Civil Engineering Laboratory to find or develop better corrosion protection for Fleet mooring buoys. The assignment included investigation of both protective coatings and cathodic protection.

A field-test program was initiated in San Diego with 15 peg-top riser-chain mooring buoys (Mark I or Mark II). Thirteen different coating systems were used, and a cathodic protection system was installed on one buoy of each of three pairs used in this part of the test program. The same thirteen coating systems were also applied to two sets of test panels, one exposed in San Diego Bay and the other in Port Hueneme Harbor. The results of the program are published in a series. Technical Report R-246,[1] the first in the series, described the application of protective coatings and the installation of a cathodic protection system. Subsequent reports[2, 3, 4, 5, 6, 7] described the condition of the buoys from the first through the sixth rating inspections and the condition of the panels through their fifth rating inspection. This report describes the condition of the buoys at the time of their seventh rating inspection and the condition of the panels after 3 years of exposure.

SERVICE CONDITIONS

For the test, 15 mooring buoys were placed in an area of North San Diego Bay that receives heavy service from the fleet. Some of the buoys were badly damaged by overriding vessels and by the abrasion of mooring lines and securing assemblies. Because it was necessary to place the test buoys in service a few at a time, and because there were long delays in obtaining acceptable specification coatings, preparation and placement of all the buoys required a long time. One set of 13 panels was suspended from a pier in San Diego Bay and the other from a pier in Port Hueneme Harbor. A portion of each panel was continuously submerged, another portion was intermittently submerged by rising tide, and a third portion was continuously exposed to the atmosphere. The panels were not exposed to their harbor environments at the same time as the buoys; they were kept in storage until all of them had been coated. All the panels were then placed in test position at the same time, rather than over a 6-month period as were the buoys. At the time of their sixth rating (described herein) they had been exposed for 3 years.

INSPECTION PROCEDURE

Each of the test mooring buoys was inspected after it had been lifted onto the deck of a floating crane. The amount of fouling was determined, the types of organisms were recorded, and fouling damage to the coating was noted. After the fouling was examined, the cone and splash zone of each buoy was washed with a high-pressure stream of seawater to remove the fouling and expose coating damage. Two independent ratings of the condition of each buoy and its protective coating system were made in the atmospheric, splash, and submerged zones.

Electrical potential measurements were made on buoys with and without cathodic protection to determine the amount of additional potential produced on cathodically protected buoys. The coating deterioration and corrosion damage of the three cathodically protected buoys were compared to those of the control buoys.

Two independent ratings were also made of the condition of the coating systems on the steel test panels exposed in San Diego Bay and Port Hueneme Harbor. Fouling organisms were carefully removed from one side of each test panel with a wooden scraper and a stiff brush before rating the coating condition in the fouled area.

RATING CRITERIA

So far as possible, the methods of rating the coatings on buoys and test panels were those published by the American Society for Testing and Materials.[8] These published methods define the conditions rated and give photographic reference standards. Thus, chalking, blistering, checking, cracking, flaking, erosion, and rusting were rated from 0 to 10 by ASTM methods D-659-44, D-714-56, D-660-44, D-661-44, D-772-47, D-662-44, and D-610-43, respectively. A rating of 10 usually describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. Blistering frequency was rated as none (N), few (F), medium (M), medium dense (MD), or dense (D). Surface areas covered by fouling (plant, animal, or combined fouling) were rated from 0 (100% covered) to 10 (0% covered). Color of the topcoat on the buoys was also rated from 0 to 10; 10 indicates pure white with no yellowing or other discoloration (except rust streaks from uncoated bolts), and 0 indicates a color unacceptable to the U. S. Coast Guard.

Frequency of use of buoys by the Fleet was rated as light (0 to 2 days per week), medium (2 to 4 days per week), or heavy (4 to 7 days per week). Some of the buoys provide bow and stern mooring only, and the rest provide either bow and stern or free-swinging moorings.

The overall condition of each buoy and its coating system was rated as excellent (in essentially the same condition as when first placed in service); good (very minor deterioration); fair (a significant amount of coating deterioration and/or rusting, but still in serviceable condition); and poor (coating deterioration and rusting serious enough to lead to an early removal from service).

The coating system on each test panel was given an overall rating from 0 (minimum protection) to 10 (maximum protection), depending upon both the condition of the entire coating system and the protection afforded to the steel. It was much easier to rate the overall coating conditions on the panels than on buoys because the panels were not abraded as were the buoys during mooring service.

CONDITION OF BUOY COATINGS

General

Table 1 describes each coating system. The overall ratings and lengths of service of buoy coatings are summarized in Table 2. The sources of the proprietary coatings tested are listed in References 2 through 4. These reports are available only to U. S. Government agencies and their contractors with a need to know. Ratings of specific conditions of coated test buoys are given in Appendix A.

The fouling on all test buoys was generally similar both in type and amount, with slightly differing amounts occurring in different test areas. Green algae and barnacles were most conspicuous in the splash zone. Tunicates and barnacles were most conspicuous in the submerged zone, and mussels, bryozoa, hydroids, and tube worms were usually present to a lesser extent.

The Mark I test buoys usually had marine borer damage on their lower, untreated wooden fenders. The lower, creosoted fenders of the larger Mark II buoys were almost always completely out of the water and suffered no marine borer attack.

Coating System 1: Urethane

The condition of the System 1 buoy (Figure 1) had changed only slightly since the previous rating inspection. The small blisters in the splash zone noted in that inspection had slight rusting around their edges (Figure 2) and accounted for most of the rusting in this area.

The many patches of underwater-curing epoxy[9] that had been applied 3 years earlier to underwater areas damaged by the impact of moored vessels were still adhering tightly to the underlying steel (Figure 3) despite the previously reported[3, 4, 5, 6, 7] lifting of the edges of some of these patches.

Coating System 2: Epoxy

The condition of the System 2 buoy (Figure 4) was essentially unchanged since the last inspection. The two areas with impact damage that had been patched with underwater-curing epoxy at the time of the last inspection[7] were receiving full protection from these patches (Figure 5). Aside from the previously noted[5] areas of slight rusting caused by abrasion, System 2 was providing good protection.

Table 1. System Description and Coating Thickness

System		Primer			Additional Coats			Total Thickness (mils)
Number	Description	Type	Coats (No.)	Thickness (mils)	Type	Coats (No.)	Thickness (mils)	
1	Urethane	Urethane	1	2	Urethane	3	8	10
2	Epoxy	Epoxy	1	4-5	Epoxy	1	4	8-9
					Epoxy	1	3	11-12
					Antifouling	1	4	15-16
3	Epoxy - Polyester	Epoxy	1	4-5	Polyester	2	5-6	9-11
					Antifouling	1	4	13-15
4	Epoxy - Coal Tar Epoxy	Epoxy	1	4	Coal Tar Epoxy	1	4-5	8-9
					Epoxy	1	4	12-13
					Epoxy	1	4	16-17
5	Coal Tar Epoxy - Phenolic	Coal Tar Epoxy	1	5	Phenolic	1	4-6	9-11
					Phenolic	1	6-7	15-18
6 & 6C	Phenolic Mastic	Mica-filled Phenolic	1	10-11	Phenolic Mastic	1	8-9	18-20
7C	Phenolic	Wash Primer	1	½	Phenolic	1	2-3	7-8
		Phenolic	2	4 ½	Antifouling	1	3	8
8	Phenolic - Alkyd	Wash Primer	1	½	Alkyd	1	2-3	7-8
		Phenolic	2	4 ½	Antifouling	1	3	8
9	Vinyl	Wash Primer	1	½	Vinyl - alkyd	3	4	11-12
		Vinyl	4	6 ½ - 7 ½	Antifouling	2	4	11-12
10	High-Body Vinyl	Vinyl	1	2	Vinyl	2	5-6	7-8
					Vinyl	1	2	9-10
11	Vinyl Mastic	Vinyl Phenolic	1	1-2	Vinyl Mastic	2	12-13	13-15
12	Inorganic Zinc Silicate - Vinyl Mastic	Inorganic Zinc	1	4	Vinyl Mastic	1	5-6	10-12
		Silicate - Vinyl Phenolic	1	1-2				
13 & 13C	Saran (Formula 113/54)	—	—	—	Saran	8	8	8

Table 2. Overall Rating and Length of Service for Coated Buoys

Coating System		Length of Service (days)	Overall Rating
Number	Description		
1	Urethane	1,320	good-fair
2	Epoxy	1,280	good
3	Epoxy-Polyester	1,280	fair
4	Epoxy-Coal Tar Epoxy	1,320	good-fair
5	Coal Tar Epoxy-Phenolic	1,278	fair
6	Phenolic Mastic	1,278	good-fair
6C	Phenolic Mastic	1,278	good
7C	Phenolic	1,133	good-fair
8	Phenolic-Alkyd	1,133	good-fair
9	Vinyl	1,155	good-fair
10	High-Body Vinyl	—	removed from test
11	Vinyl Mastic	—	removed from test
12	Inorganic Zinc Silicate-Vinyl Mastic	1,320	fair-poor
13	Saran	1,279	good-fair
13C	Saran	1,287	good

Figure 1. System 1 buoy after removal of fouling.

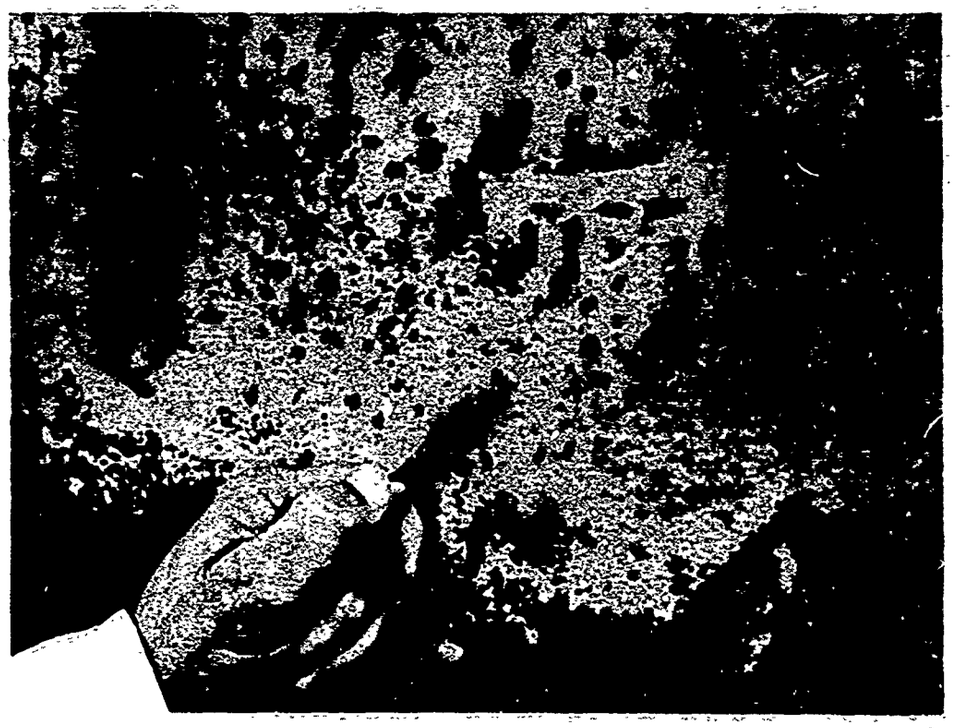

Figure 2. Rusting associated with blistering on System 1 buoy.

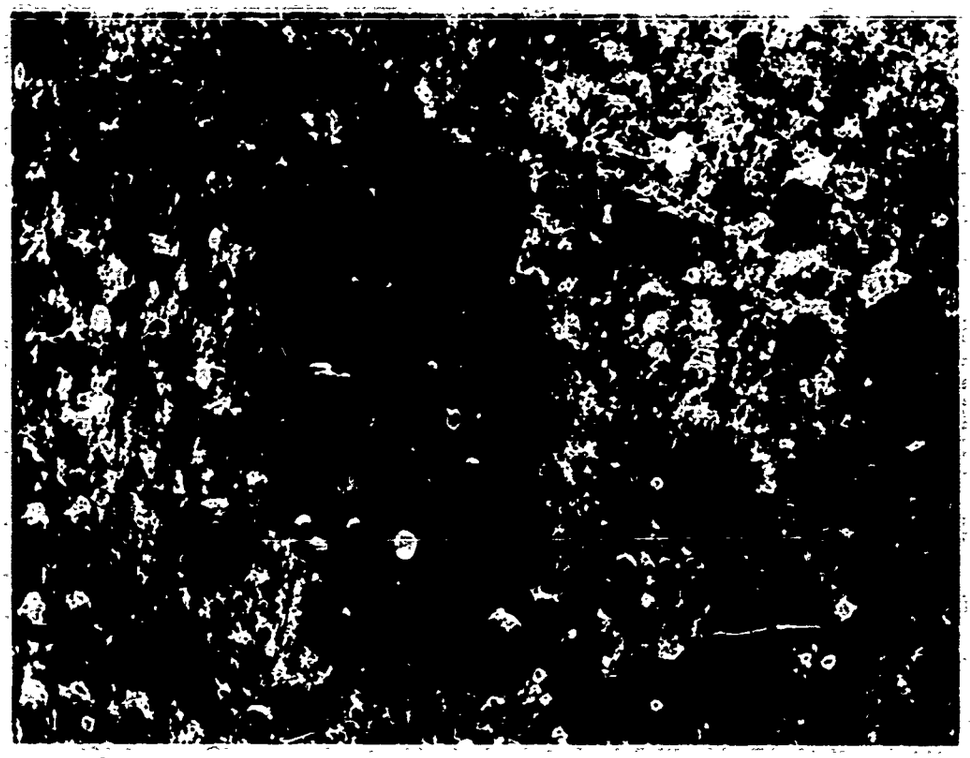

Figure 3. Epoxy patch on cone of System 1 buoy. Note barnacle fouling on patch.

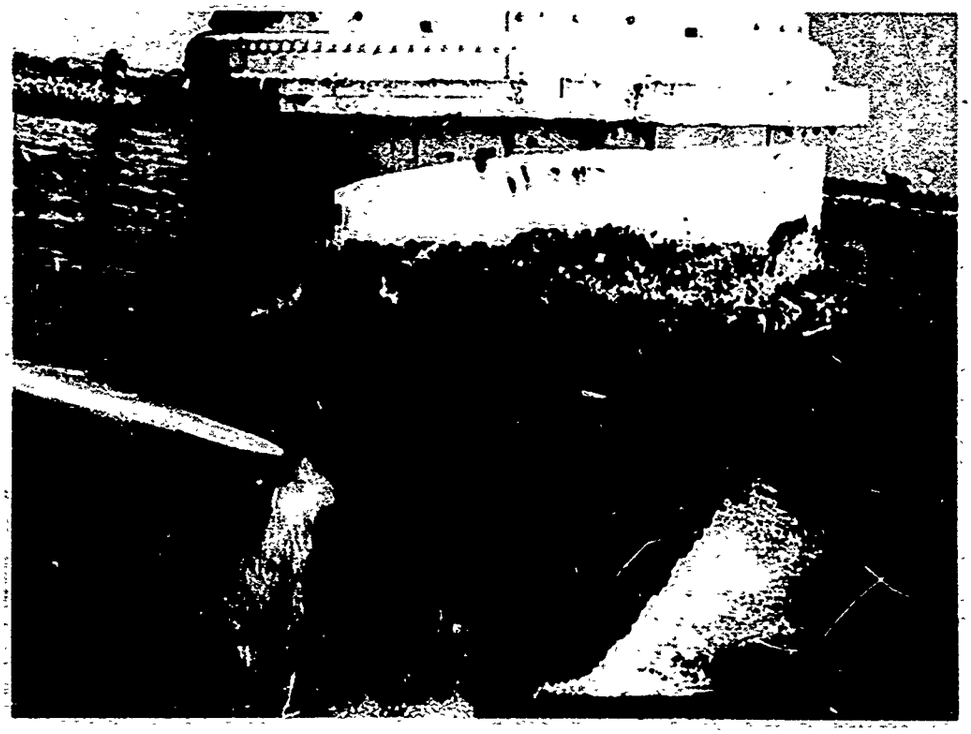

Figure 4. Hosing fouling from System 2 buoy.

Figure 5. Epoxy patch on cone of System 2 buoy.

Coating System 3: Epoxy-Polyester

The condition of the System 3 (Figure 6) buoy was essentially unchanged from that noted at the last inspection. The epoxy primer exposed in the submerged zone where much of the polyester topcoats had delaminated was continuing to protect the underlying steel. The rusting in all three zones was related to abrasion damage.

Coating System 4: Epoxy-Coal Tar Epoxy

The condition of the System 4 buoy (Figure 7) was essentially unchanged since the last inspection. The previously noted delamination of the topcoat and seal coat in the submerged zone had not advanced significantly since the last inspection, and the underlying epoxy primer and coal tar epoxy were providing good protection to the steel. Elsewhere, the entire coating system was performing well.

Coating System 5: Coal Tar Epoxy-Phenolic

Aside from some additional top rusting initiated by the abrasive action of the securing assembly, the condition of the System 5 buoy (Figure 8) was essentially unchanged since the last inspection. Most of the coating damage in the atmospheric and splash zones was related to abrasion damage.

Coating Systems 6 and 6C: Phenolic Mastic

Systems 6 and 6C were identical but the 6C coating was applied to a cathodically protected buoy. Aside from some additional top rusting initiated by the abrasive action of the securing assembly, the condition of both buoys (Figure 9) was essentially unchanged since the last inspection. The System 6 buoy was in slightly poorer condition than the 6C buoy due in large part to its lighter fendering and lack of cathodic protection.

Coating System 7C: Phenolic

The condition of the System 7C buoy (Figure 10) had not changed appreciably since the last inspection. The medium blistering previously noted[6, 7] in the submerged zone had not increased appreciably. There was also some flaking of the coating in this area (Figure 11). This may have resulted from the blistering or from barnacle attachment, since the antifouling coating was no longer effective. The cathodic protection system on this buoy was very effective in mitigating rusting where bare steel was exposed in the underwater portion. Pinpoint rusting occurred in the splash zone.

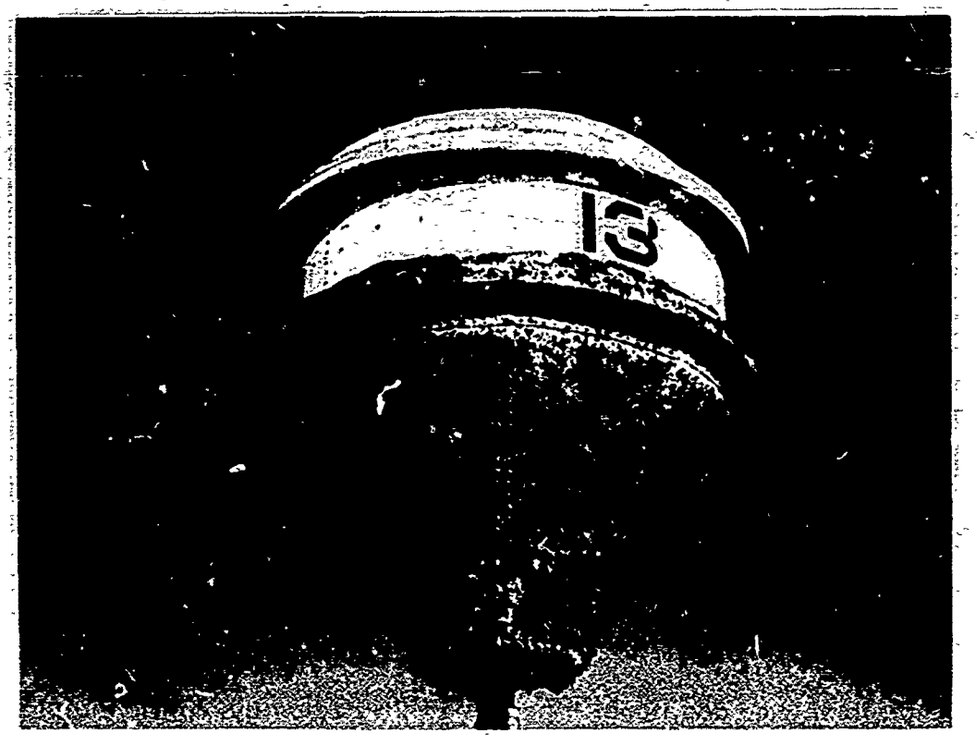

Figure 6. System 3 buoy after removal of fouling.

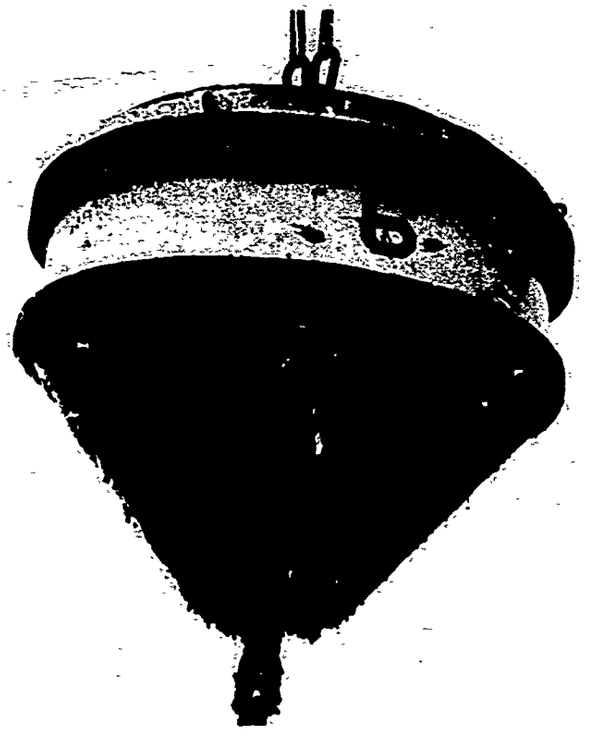

Figure 7. System 4 buoy after removal of fouling.

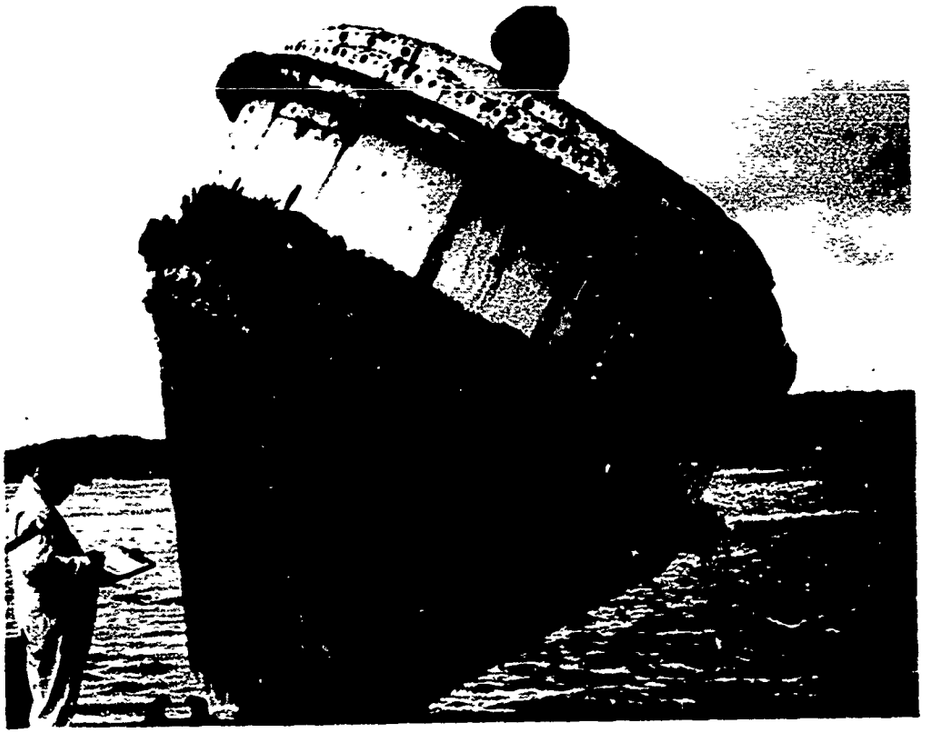

Figure 8. System 5 buoy after removal of fouling.

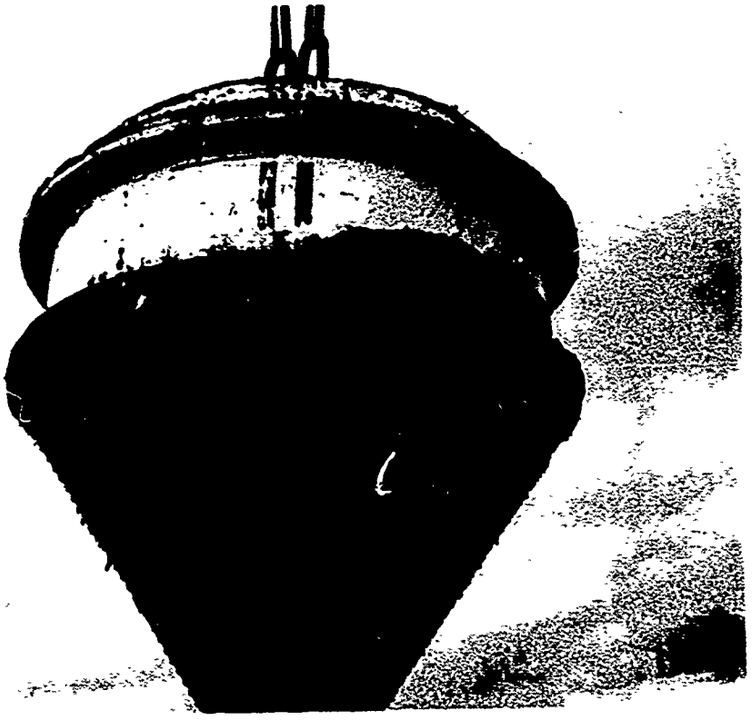

Figure 9. System 6 buoy after removal of fouling.

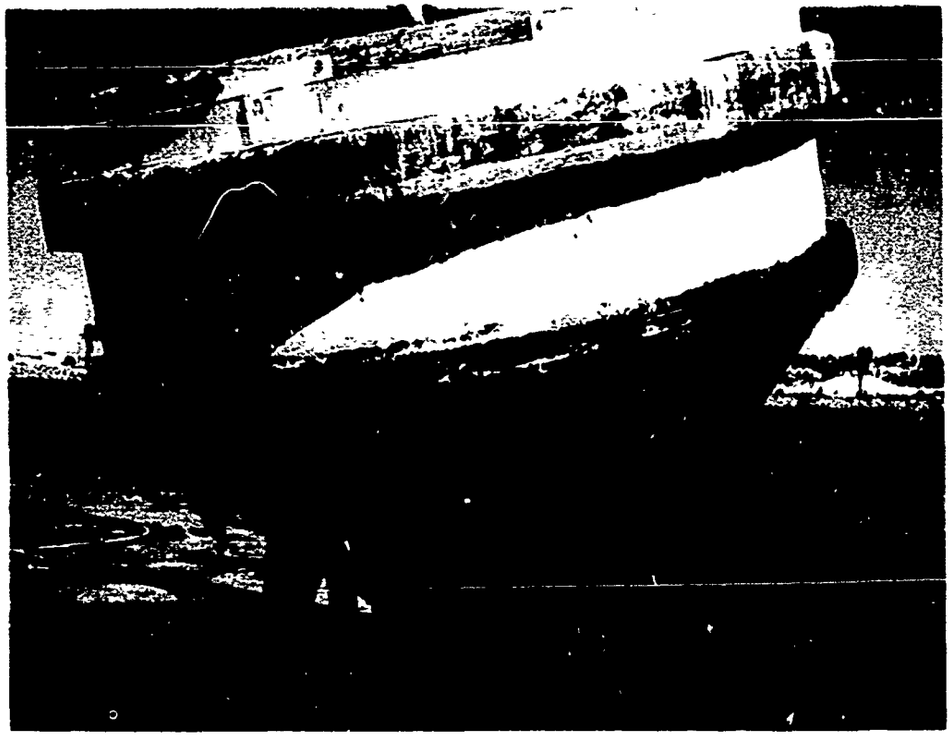

Figure 10. System 7C buoy after removal of fouling.

Figure 11. Flaking of coating from cone of System 7C buoy.

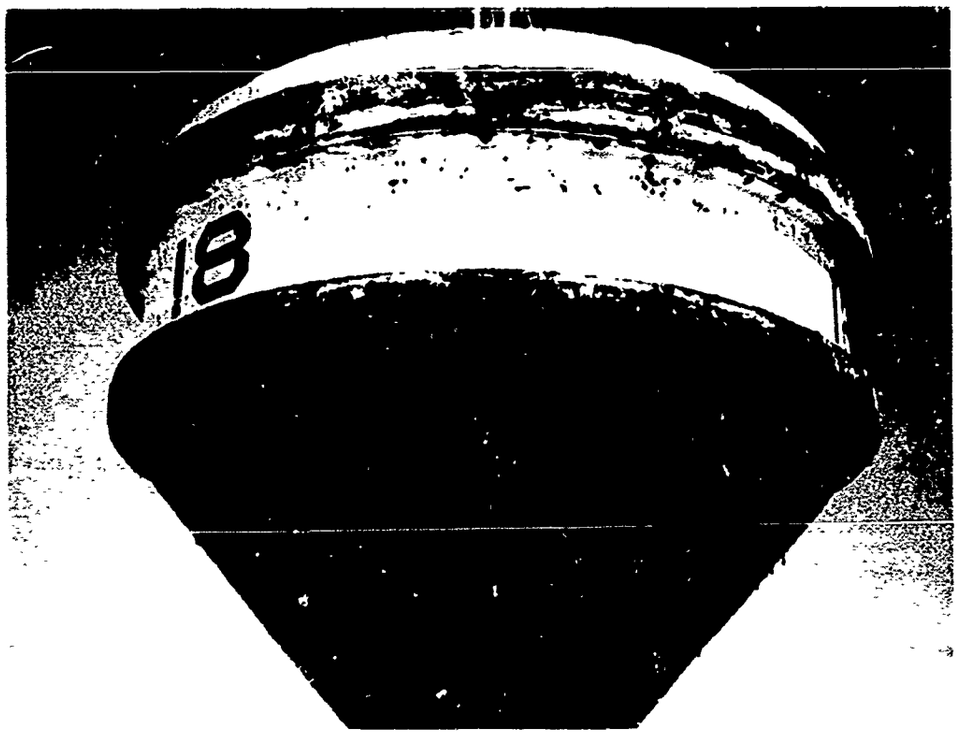

Figure 12. System 8 buoy after removal of fouling.

Coating System 8: Phenolic-Alkyd

The condition of the System 8 buoy (Figure 12) had not changed greatly since the last inspection. The submerged portion of this buoy had the identical coating system used on the System 7C buoy, and the condition of the coating system in the submerged zone on both buoys was essentially the same. There was, however, more rusting of steel in this area of the System 8 buoy since it did not receive cathodic protection. Rusting on the side of the buoy was either of the pinpoint variety or had been caused by abrasion.

Coating System 9: Vinyl

The System 9 buoy had damaged areas on two side flanges that were patched with underwater-curing epoxy[9] at the time of the last buoy inspection.[7] Although this particular epoxy sagged slightly at the time of application, the two patches were in good condition (Figure 13) and were providing protection to the steel. There were two additional side flange areas and one area away from flanges on the side of the buoy that required patching. The coating adjacent to the damaged areas pulled away from the steel rather easily, but there was no rusting under the loose coating.

There were also eight small spots on the underwater portion of the buoy (Figure 14) that required patching. It appeared that some of these areas had resulted from abrasion. All abraded areas were patched with underwater-curing epoxy (Figure 15) before the buoy was returned to service. Aside from the damaged areas, the coating system had not greatly changed since the last inspection (Figure 16). The type and amount of fouling on this buoy were similar to those on test buoys without an anti-fouling coating.

Coating System 10: High-Body Vinyl

Because of advanced corrosion, the System 10 buoy was removed from testing before this rating inspection.

Coating System 11: Vinyl Mastic

Because of advanced corrosion, the System 11 buoy was removed from testing before this rating inspection.

Coating System 12: Inorganic Zinc Silicate - Vinyl Mastic

The condition of System 12 buoy had deteriorated somewhat since the last inspection. The slight rusting on the top and side was caused by abrasion damage. Although half of the organic primer and topcoat had been lost from the submerged portion during the first 6 months, the underlying inorganic zinc silicate coating had been effective in mitigating corrosion. The gradual loss of zinc has resulted in increased rusting in this area (Figure 17). The rusting thus far has been light and free of pitting.

Coating Systems 13 and 13C: Saran

Systems 13 and 13C were identical, but System 13C was applied to a cathodically protected buoy. The former buoy was in the mooring yard (Figure 18) undergoing structural repair at the time of inspection. The condition of the coating on both buoys had not changed greatly since the last inspection. Most of the rusting was due to abrasion or was of the pinpoint variety. The cathodic protection on the System 13C buoy was mitigating corrosion in the submerged area (Figure 19). The square of bare steel (Figure 20) previously exposed on the cone of the System 13C buoy was covered with a thin film of loose rust and had no pitting.

Figure 13. Epoxy patch on damaged flange area of System 9 buoy.

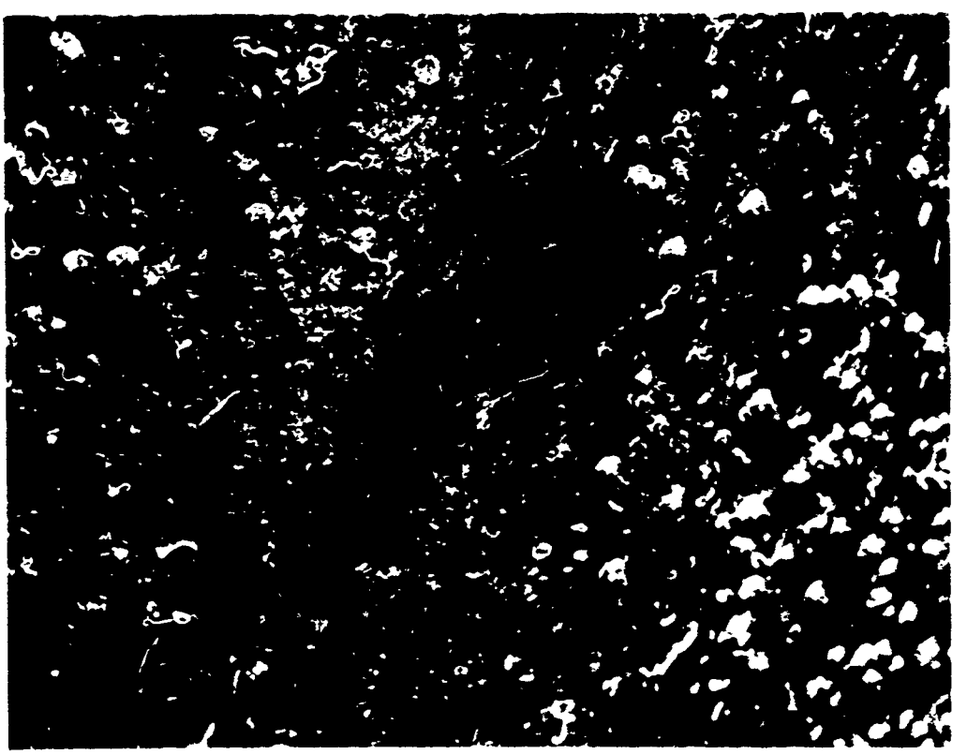

Figure 14. Damaged coating on System 9 buoy cone.

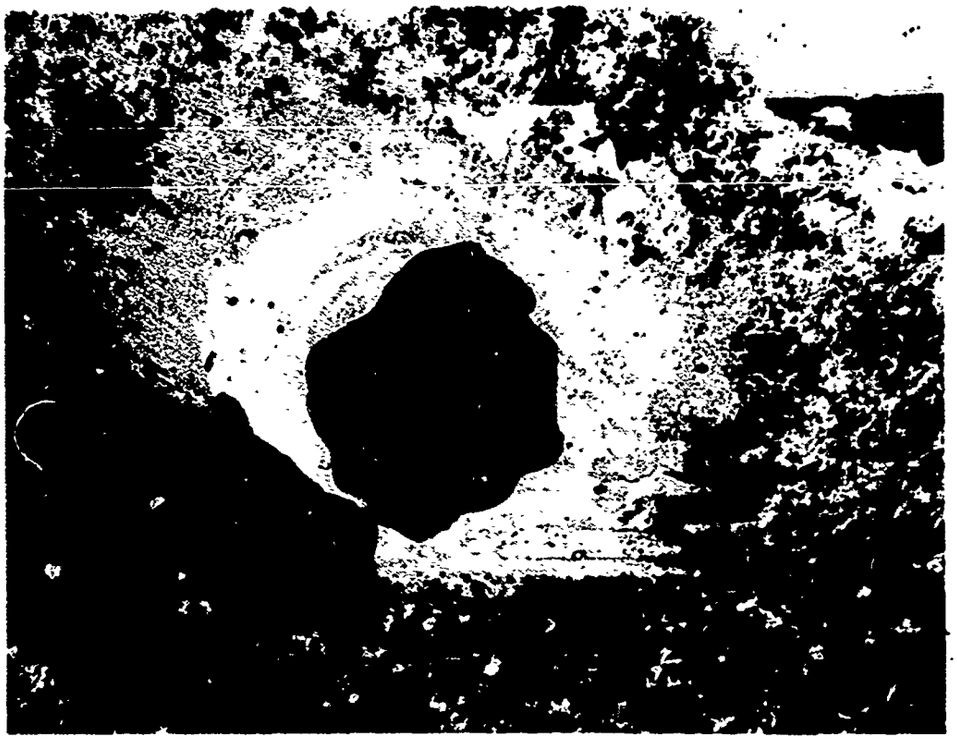

Figure 15. New epoxy patch on buoy side (center) and old epoxy patch on flange (lower left) on System 9 buoy.

Figure 16. System 9 buoy after epoxy patching.

Figure 17. Lower portion of System 12 buoy.

Figure 18. System 13 buoy in mooring yard for structural repair.

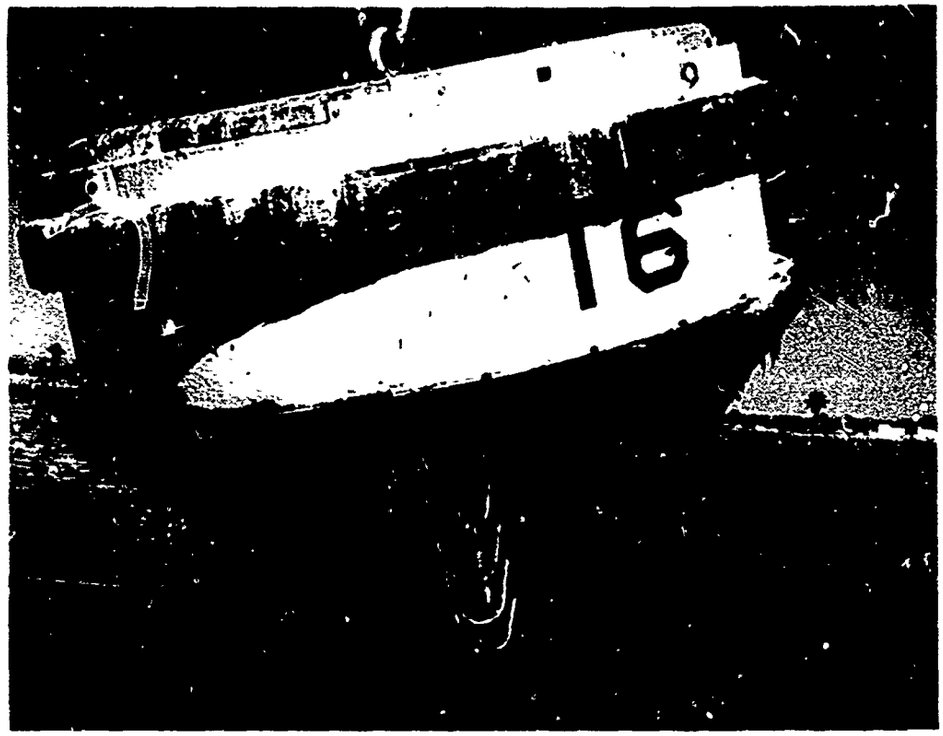

Figure 19. System 13C buoy after removal of fouling.

Figure 20. Square of bare steel on System 13C buoy. Note barnacle fouling.

CONDITION OF COATED PANELS

The coating system of each panel is rated in Table 3, and the ratings of the specific properties are given in Appendix B. There continues to be a distinct difference in the type of fouling at the two panel testing sites. While barnacles were conspicuous at both locations, especially in the tidal zone, mussels were much more numerous and larger at Port Hueneme. Bryozoa were present in appreciable amounts at Port Hueneme, but virtually absent at San Diego. Conversely, tunicates and sponges were most conspicuous at San Diego but virtually absent at Port Hueneme.

Coating System 1: Urethane

The urethane panel at San Diego was in fairly good condition, virtually unchanged since the last inspection. The Port Hueneme panel, however, had medium blistering and considerable type II rusting in the atmospheric and tidal zones. There was also some delamination of topcoats on one side of the Port Hueneme panel.

Coating System 2: Epoxy

Both epoxy-coated panels were receiving excellent protection, and no deterioration other than the previously reported[4, 5, 6, 7] loss of antifouling paint was noted. The two System 2 panels that had later been painted below the water line with antifouling paints (one with a proprietary copper oxide-containing polyester and the other with vinyl antifouling -- MIL-P-15931A) and exposed in Port Hueneme Harbor[7] were performing well with no appreciable fouling after 1 year.

Coating System 3: Epoxy-Polyester

As previously reported,[4, 5, 6, 7] when the antifouling coating (identical to that of System 2) was lost from the System 3 panels, it took the polyester coats with it, thus exposing the underlying epoxy primer. This primer continues to provide protection at both locations. Most of the slight rusting present occurs along the edges. The previously noted[7] blisters on the San Diego panels have been lost, thereby exposing additional primer.

Coating System 4: Epoxy-Coal Tar Epoxy

Neither System 4 panel has shown any deterioration other than slight edge rusting on the San Diego panel.

Table 3. Overall Ratings of Coated Panels After 3 Years

Coating System		Rating[1]	
Number	Description	Port Hueneme	San Diego
1	Urethane	8	9
2	Epoxy	10	10
3	Epoxy - Polyester	9	9
4	Epoxy - Coal Tar Epoxy	10	10
5	Coal Tar Epoxy - Phenolic	9	9
6	Phenolic Mastic	10	10
7C	Phenolic	9	9
8	Phenolic - Alkyd	9	9
9	Vinyl	10	10
10	High-Body Vinyl	7	7
11	Vinyl Mastic	6	6
12	Inorganic Zinc Silicate - Vinyl Mastic	9	8
13	Saran	9	9

[1] 10 = perfect condition; 0 = complete deterioration

Coating System 5: Coal Tar Epoxy-Phenolic

On both System 5 panels, there was almost complete loss of the white topcoat in the tidal and submerged zones, exposing the underlying seal coat. This was caused by blistering and delamination. The seal coat and underlying coal tar epoxy were providing good protection at both locations; slight rusting occurred at panel edges.

Coating System 6: Phenolic Mastic

The System 6 panel showed no deterioration in any zone at Port Hueneme and only slight edge rusting in the submerged zone at San Diego.

Coating System 7C: Phenolic

There were numerous small blisters in the submerged zone of both System 7C panels, but no rusting was associated with the blistering. Ever greater amounts of the underlying primer continue to be exposed by the gradual erosion of the black antifouling coating. Fouling continues to be appreciably less on the System 7C panels than on adjacent panels without an antifouling coating.

Coating System 8: Phenolic-Alkyd

System 8 is identical to 7C in the tidal and submerged zones; consequently, the conditions of the two coating systems in these areas were similar. The coatings in the atmospheric zones of these systems, though different, were both providing relatively good protection.

Coating System 9: Vinyl

Neither System 9 panel showed appreciable deterioration in any zone, except for a partial erosion of the antifouling coating, exposing some of the underlying primer. The fouling continues to be appreciably less on System 9 panels than on adjacent panels without an antifouling coating.

Coating System 10: High-Body Vinyl

Both System 10 panels had extensive rusting (both types I and II) and pitting, and the coatings are rated as failed. Consequently, they will be removed from testing.

Coating System 11: Vinyl Mastic

Both System 11 panels were removed from test at the time of the last inspection because of coating failure.

Coating System 12: Inorganic Zinc Silicate - Vinyl Mastic

On the Port Hueneme panel, 60% of the vinyl mastic coating had been lost in the tidal zone and 20% in the submerged zone at time of inspection. The exposed zinc silicate coating, however, was providing good protection, and there was no rusting in any zone. The San Diego panel had lost most of i.s topcoating in the tidal and submerged zones and there was rusting and an indication of pitting in these areas.

Coating System 13: Saran

Both Saran 13 panels were in relatively good condition. Most of the corrosion present consisted of pinpoint or edge rusting.

CATHODIC PROTECTION RESULTS

As previously reported,[7] shortly before the previous inspection, all test buoys were picked up and relocated. Because of the tightness of the mooring chains, some of the cathodic protection was transferred from the cathodically protected buoys down the riser chain as has been shown[10] to occur with tight moorings. Potentials measured at the time of the inspection of System 6C, 7C, and 13C buoys were -870, -780, and -820 mv, respectively, as compared to the potentials of a standard silver/silver chloride half-cell. These potentials are quite similar to those recorded at the time of the last inspection, namely -810, -770, and -840 mv, respectively. These potentials for cathodically protected buoys are considerably above the potentials of the unprotected buoys, which have an average value of -670 mv. They are also close to or above the minimum value (-800 mv) considered to be necessary for adequate protection. The riser chains of the protected buoys (Figure 21) had considerably less corrosion and coating loss than the riser chains of the buoys without cathodic protection (Figure 22). The riser chains of the latter had alternate areas of bright and rusted steel indicating active corrosion, while the rust that occurred on the former was in a thin, uniform layer.

The square of bare steel previously exposed by power wire brushing[3, 4, 5, 6, 7] on the cone of the System 13C buoy had only a very thin layer of black rust and no indication of pitting. Some of this area had barnacle fouling. The cathodically protected buoys had less rusting than the corresponding unprotected control buoys, and the rust was present in a thin, uniform layer. After removal of the loose, yellowish film from the sacrificial zinc anodes during the high-pressure hosing of the buoy fouling, the anode surfaces were clean and crystalline in appearance. This condition is normal for properly functioning zinc anodes, and no signs of passivation were noted. Relatively little zinc had been lost from the anodes (Figure 23) in protecting the test buoys since the last inspection, and they should continue to provide protection for a long time before anode replacement becomes necessary.

Figure 21. Riser chain linkages on System 13C buoy.

Figure 22. Riser chain linkages on System 8 buoy.

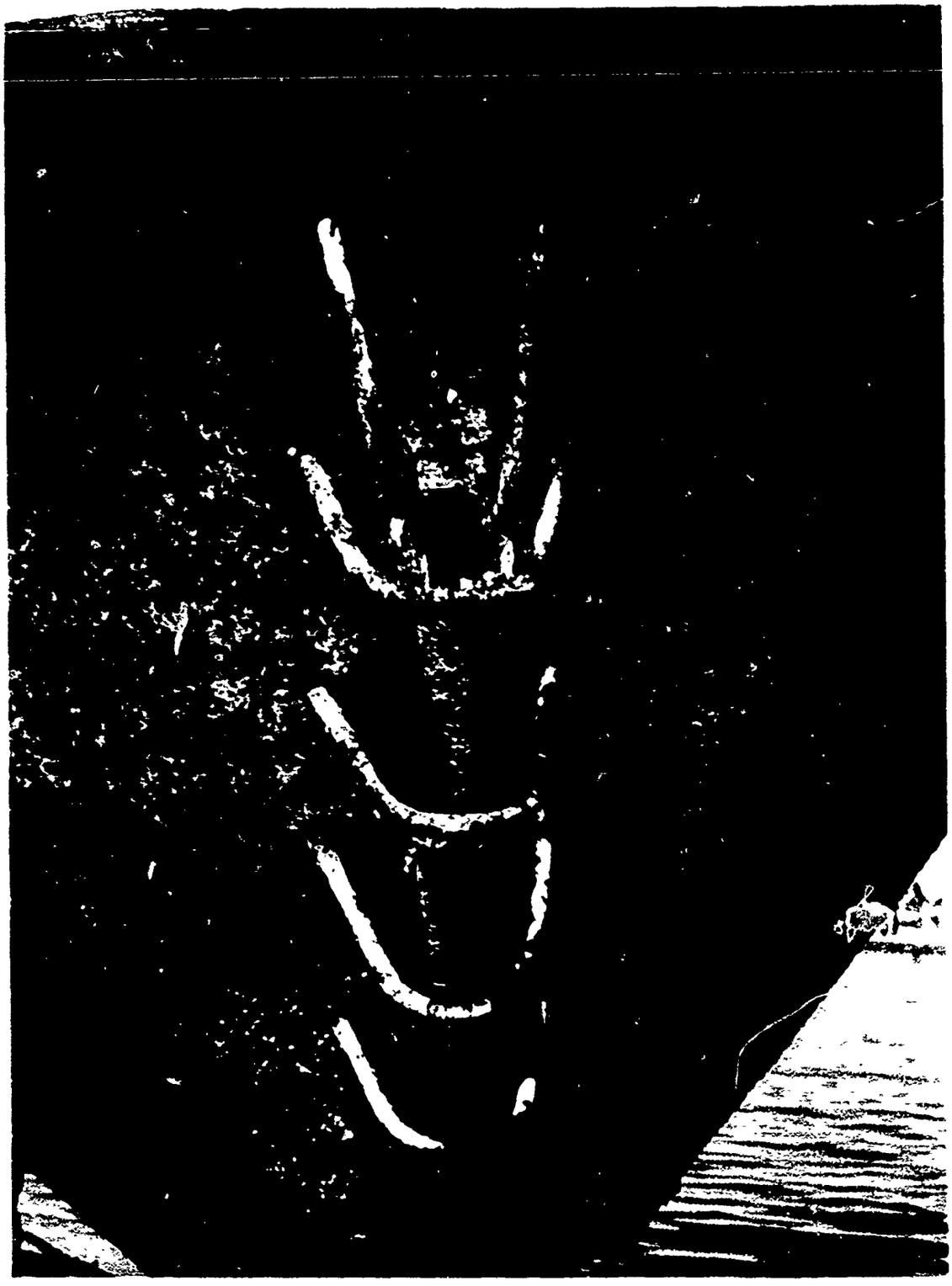

Figure 23. Zinc anode on System 13C buoy.

DISCUSSION

The condition of the buoy coating systems at the time of each inspection is summarized in Table 4. It can be seen from this table that relatively little change occurred during the last 6 months.

At the time of the present inspection, the System 2 (epoxy) buoy was in the best condition. Patches of epoxy on this buoy are providing good protection to the two areas that had previously[7] suffered impact damage.

Two of the cathodically protected buoys (6C and 13C) were also rated in good condition. Because the 6 and 6C buoys had previously suffered extensive abrasion damage, it first appeared that Coating System 6 (phenolic mastic) might be especially susceptible to abrasion. Further exposure has not substantiated this. Buoy 13C (Saran) has slight pinpoint rusting in the atmospheric and splash zones but virtually none in the submerged zone, which was given the cathodic protection. The phenolic mastic and Saran systems have performed very well in the steel sheet piling study of Alumbaugh and Brouillette.*

Coating Systems 2 (epoxy), 6 (phenolic mastic), and 9 (vinyl) were in good condition on both sets of test panels and on the buoys. Panels coated with Systems 4 (epoxy - coal tar epoxy) and 9 were also in good condition on test panels, but the System 4 buoy had lost much of the epoxy seal and topcoats in the submerged area, and the System 9 buoy had 11 small areas with damage to the coating of unknown origin. The areas on the System 4 buoy where the seal and topcoats had been lost were receiving good protection from the underlying epoxy primer and coal tar epoxy. A two-coat system of this primer and coal tar epoxy is currently being used routinely on steel-pontoon camel floats.

Coating System 1 (urethane) is in fairly good condition but does have appreciable rusting associated with blistering in the splash zone.

Coating System 3 (epoxy - polyester) is providing good protection to both the buoy and panels despite the loss of much of the polyester topcoating in the submerged zones. The epoxy primer providing this protection is identical with the one used in Coating System 2.

The System 5 buoy (coal tar epoxy - phenolic) suffered much abrasion damage during the first 6 months but has had very little further abrasion damage since then. Much of the topcoat had previously been lost from the tidal and submerged zones of both System 5 panels.

Coating Systems 7C (phenolic) and 8 (phenolic - alkyd) are in relatively good condition on both the test panels and buoys, except for the medium blistering in the submerged zone. The flaking of coating noted in this area may have resulted in part from the high-pressure hosing used to remove fouling organisms. The blistering and fouling previously described may also have contributed to this condition.

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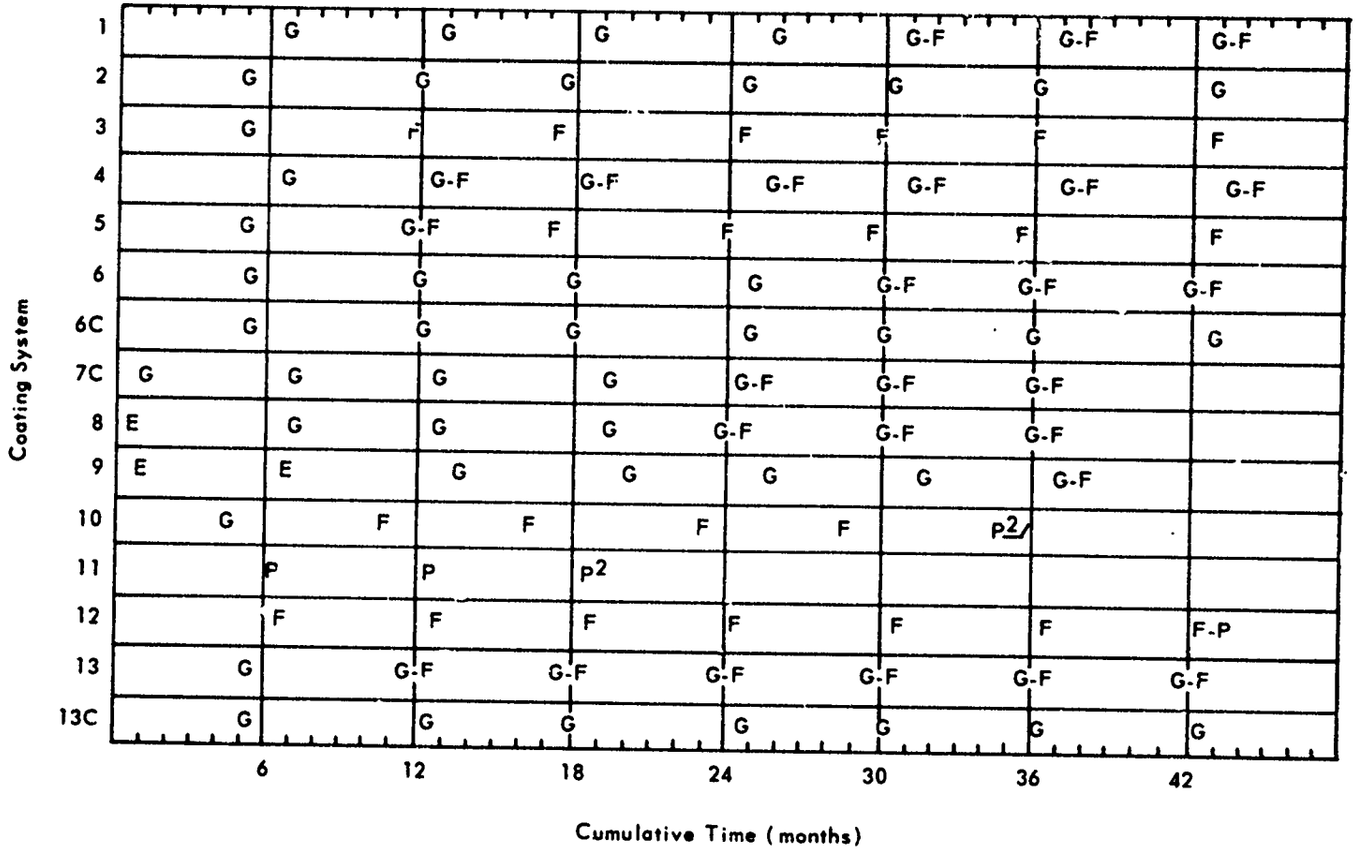
* U. S. Naval Civil Engineering Laboratory. Protective coatings for steel piling: Results of harbor exposure on 10-foot simulated piling, by R. L. Alumbaugh and C. V. Brouillette. Port Hueneme, Calif. (Manuscript in preparation).

Table 4. Condition of Buoy Coatings at Time of Each Inspection[1]



[1] Ratings:
E = excellent
G = good
F = fair
P = poor

[2] Removed from test after failure.

The System 12 (inorganic zinc silicate - vinyl mastic) buoy continues to increase in rusting in the submerged zone. The inorganic zinc coating exposed where the vinyl mastic topcoating had previously delaminated has gradually eroded away in sacrificially protecting the steel.

As the test coating systems continue to provide satisfactory protection to the buoys, the use of an antifouling coating becomes increasingly difficult to justify. The effectiveness of such coatings in mitigating fouling falls off markedly after 2 years, and none of the better performing coatings show any signs of fouling damage. No decrease in freeboard has been noted since the buoys were first placed into service.

The zinc anodes appear to be quite effective in mitigating buoy corrosion where bare steel is exposed below the water line. The average potential of the cathodically protected buoys is somewhat lower than desired (-850 mv) because the protection extends to some extent down the tight riser chains. The buoys, however, are receiving a high level of protection and in addition, the riser chains of cathodically protected buoys are in noticeably better condition than those of the unprotected buoys. The cathodic protection of buoys and ground tackle is being investigated and reported separately.[10] No evidence was found of the passivation of zinc anodes previously noted in San Diego Bay by Peterson and Waldron.[11]

FINDINGS

1. On three of the test buoys, the coating systems were in good condition; 10 others showed varying degrees of intermediate deterioration; and two had deteriorated so badly that the buoys were removed from testing before rating inspection.

2. Two antifouling paints on test panels were still effective in reducing the amount of fouling to an appreciable extent after 3 years; on the test buoys they had lost most of their effectiveness after 20 months.

3. Patches of underwater-curing epoxy applied to areas of damaged coating as long as 3 years previously were effectively protecting the steel below the water line.

4. Zinc anodes were effective in mitigating corrosion on test buoys. Some protection was transferred to the tight riser chain.

CONCLUSIONS

1. Underwater-curing epoxies (so-called "splash zone compounds") can be very effective for repairing localized areas of coating damaged by abrasion and thus extending the service period of mooring buoys until overhaul.

4/ Removed from test after failure.

2. Zinc anodes can be used effectively to mitigate corrosion below the water line on mooring buoys or other floating structures.

3. The use of an antifouling paint on the underwater portion of mooring buoys is not justified, unless fouling is known to be a problem.

ACKNOWLEDGEMENT

Mr. C. V. Brouillette of NCEL made an independent rating of the coated buoys and both sets of test panels.

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Appendix A

RATINGS OF BUOYS WITH TEST COATINGS

Coating System 1: Urethane

No. of Days in Service: 1, 320 — Overall Condition: Good-Fair

Amount of use: Heavy — Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	2	2	—
Blistering	N, 10	M, 4	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I[1]	9	9	9
Rusting, Type II[2]	10	10	10
Fouling, amount	—	M	M
Guano, amount	L	—	—
Structural damage	N	broken fender	dent in steel plate

[1] Without blistering.
[2] With blistering.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 usually describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 2: Epoxy

No. of Days in Service: 1,281 Overall Condition: Good

Amount of use: Light Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	6	6	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	—
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	9	9	9
Rusting, Type II	10	10	10
Fouling, amount	—	H	H
Guano, amount	M	—	—
Structural damage	N	N	dent in steel plate

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 usually describes a perfect condition and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 3: Epoxy-Polyester

No. of Days in Service: 1,280 Overall Condition: Fair

Amount of use: Light Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	8	8	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	5[1]	5[1]
Erosion	10	10	10
Rusting, Type I	9	9	9
Rusting, Type II	10	10	10
Fouling, amount	—	H	H
Guano, amount	H	—	—
Structural damage	fender splintered	N	fender splintered

[1] Topcoat lost, primer exposed.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 usually describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 4: Epoxy-Coal Tar Epoxy

No. of Days in Service: 1,320 Overall Condition: Good-Fair

Amount of use: Heavy Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	6	6	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	6 1/
Erosion	10	10	10
Rusting, Type I	9	9	9
Rusting, Type II	10	10	10
Fouling, amount	—	M	M
Guano, amount	L	—	—
Structural damage	N	N	N

1/Delamination of topcoat and seal coat, exposing coal tar epoxy coating.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 usually describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 5: Coal Tar Epoxy-Phenolic

No. of Days in Service: 1,278 Overall Condition: Fair

Amount of use: Light Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	8	8	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	6[1]	9	9[2]
Rusting, Type II	10	10	10
Fouling, amount	—	H	H
Guano, amount	L	—	—
Structural damage	N	N	dent in steel plate

1/ Mostly from abrasion of coating by securing assembly.
2/ Rivet heads were badly corroded.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 usually describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 6: Phenolic Mastic

No. of Days in Service: 1,278 Overall Condition: Good-Fair

Amount of use: Light Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	8	8	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	8[1]/	9[1]/	9[1]/
Rusting, Type II	10	10	10
Fouling, amount	—	H	H
Guano, amount	L	—	—
Structural damage	dent in side; broken fender	broken fender	dent in steel plate

[1]/Mostly from abrasion of coating.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 usually describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 6C: Phenolic Mastic

No. of Days in Service: 1,278 Overall Condition: Good

Amount of use: Light Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	10	10	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	7[1/]	9[1/]	9[1/]
Rusting, Type II	10	10	10
Fouling, amount	—	L	M
Guano, amount	L	—	—
Structural damage	fender splintered	N	N

[1/] Mostly from abrasion of coating.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 usually describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 7C: Phenolic

No. of Days in Service: 1,133 — Overall Condition: Good-Fair

Amount of use: Light — Type of Mooring: Free-Swinging

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	6	6	—
Blistering	N, 10	N, 10	M, 4
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	9
Erosion	10	10	8[1]
Rusting, Type I	9[2]	9[2]	10
Rusting, Type II	10	10	10
Fouling, amount	—	L	M
Guano, amount	M	—	—
Structural damage	N	N	slight dent in steel plate

[1] Antifouling paint only.
[2] Mostly from abrasion of coating.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 usually describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 8: Phenolic-Alkyd

No. of Days in Service: 1,133 — Overall Condition: Good-Fair

Amount of use: Light — Type of Mooring: Free-Swinging

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	10	10	—
Blistering	N, 10	N, 10	M, 4
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	8
Erosion	10	10	9[1]
Rusting, Type I	9[2]	9[2]	9
Rusting, Type II	10	10	9
Fouling, amount	—	M	M
Guano, amount	L	—	—
Structural damage	N	N	N

1/Antifouling paint only.
2/Mostly from abrasion of coating.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 usually describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 9: Vinyl

No. of Days in Service: 1,155 — Overall Condition: Good-Fair

Amount of use: Light — Type of Mooring: Free-Swinging

Condition Rated	Atmospheric	Splash	Submerged
Color	9	10	—
Chalking	8	8	—
Blistering	N, 10	N, 10	N, 10
Checking	N, 10	10	10
Cracking	N, 10	10	10
Flaking (scaling)	N, 10	9[1]	10
Erosion	N, 10	10	9[2]
Rusting, Type I	9	9	9
Rusting, Type II	10	10	10
Fouling, amount	—	H	M
Guano, amount	L	—	—
Structural damage	N	dent in steel plate	dent in steel plate

[1] Two areas peeled flanges and one on side.
[2] Antifouling paint only.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 usually describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 12: Inorganic Zinc Silicate - Vinyl Mastic

No. of Days in Service: 1,320 Overall Condition: Fair-Poor

Amount of use: Heavy Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	8	8	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	5[1]
Erosion	10	10	10
Rusting, Type I	9[2]	9[2]	8
Rusting, Type II	10	10	10
Fouling, amount	—	M	M
Guano, amount	L	—	—
Structural damage	N	N	dent in steel plate

[1] Topcoat only.
[2] Mostly from abrasion of coating.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 usually describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 13: Saran

No. of Days in Service: 1,279 — Overall Condition: Good-Fair

Amount of use: Light — Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	8	8	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	8[1]	9[2]	9[2]
Rusting, Type II	10	10	9
Fouling, amount	—	[3]	[3]
Guano, amount	[3]	—	—
Structural damage	N	fender splintered; dent in steel plate	N

[1] Mostly from abrasion of coating.
[2] Mostly pinpoint rusting.
[3] No fouling or guano present because buoy had been taken ashore for structural repairs.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 usually describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 13C: Saran

No. of Days in Service: 1,287 Overall Condition: Good

Amount of use: Light Type of Mooring: Free-Swinging

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	8	8	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	9	9[1]	10
Rusting, Type II	10	10	10
Fouling, amount	—	M	M
Guano, amount	M	—	—
Structural damage	dent in steel plate	dent in steel plate	N

[1] Mostly pinpoint rusting.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 usually describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System No.	1						2						3		
Exposure Site	PH			SD			PH			SD			PH		
Panel Zone	A[1]	T[2]	S[3]	A	T	S	A	T	S	A	T	S	A	T	S
General Protection	7	7	9	9	9	9	10	10	10	10	10	10	9	10	10
Chalking	—[5]	—	—	—[12]	—	—	--	—	—	—	—	—	—	—	—
Checking	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Blistering, size	6	6	10	10	10	10	10	10	10	10	10	10	10	10	10
Blistering, frequency	M[6]	M	N[9]	N	N	N	N	N	N	N	N	N	N	N	N
Flaking	10	7[7]	10	10	10	10	10	10	10	10	10	10	10	2[14]	2[14]
Cracking	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Undercutting	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Rusting, type I	9	9	9[10]	9[13]	9[13]	9[13]	10	10	10	10	10	10	9[10]	10	10
Rusting, type II	7	6	10	10	10	10	10	10	10	10	10	10	10	10	10
Pitting	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Fouling, amount	—	L[8]	H[11]	—	M	M	—	H	M	—	L	L	—	L	M
Fouling, area[4]	—	3	1	—	2	1	—	3	2	—	2	2	—	3	2
1. Plant Area	—	3	9	—	8	9	—	9	9	—	8	9	—	9	9
2. Animal Area	—	9	1	—	2	2	—	3	2	—	3	3	—	3	2
a. Tunicates	—	10	10	—	10	5	—	10	10	—	9	7	—	10	10
b. Barnacles	—	8	9	—	5	8	—	7	10	—	5	9	—	2	9
c. Mussels	—	10	2	—	10	9	—	6	7	—	9	9	—	8	9
d. Bryozoa	—	10	6	—	10	10	—	10	8	—	10	10	—	10	8
e. Hydroids	—	10	4	—	10	10	—	10	4	—	10	10	—	10	5
f. Tube Worms	—	10	9	—	10	10	—	10	9	—	10	10	—	10	9
g. Sponges	—	10	10	—	10	8	—	10	10	—	10	10	—	10	10
Overall Rating	8			9			10			10			9		

1/ A = atmospheric zone
2/ T = tidal zone
3/ S = submerged zone
4/ 0 = 100% fouled; 10 = 0% fouled
5/ impossible to determine chalking on Port Hueneme panels because of contamination at high tide with floating oil
6/ M = medium
7/ Delamination of topcoat on one side of panel
8/ L = light
9/ N = none
10/ Mostly at edge
11/ H = heavy

Appendix B — RATING OF TEST PANELS AT PORT HUENEME AND SAN DIEGO

	3						4						5							
	PH			SD			PH			SD			PH			SD			PH	
S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T
10	9	10	10	9	9	9	10	10	10	9	10	9	9	10	10	9	9	9	10	10
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	4	10	10	10	10	10	10
N	N	N	N	N	N	N	N	N	N	N	N	N	N	F[15]	N	N	N	N	N	N
10	10	2[14]	2[14]	10	1[14]	1[14]	10	10	10	10	10	10	10	1[16]	3[16]	10	0[16]	0[16]	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	9[10]	10	10	9[10]	9[10]	9[10]	10	10	10	9[10]	10	9[10]	9[10]	10	10	9[10]	9[10]	9[10]	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
L	—	L	M	—	L	M	—	H	M	—	M	M	—	H	M	—	L	H	—	M
2	—	3	2	—	1	2	—	2	1	—	2	1	—	1	1	—	1	1	—	1
9	—	9	9	—	8	9	—	9	9	—	8	9	—	7	8	—	7	9	—	9
3	—	3	2	—	2	3	—	2	1	—	2	2	—	2	2	—	3	2	—	1
7	—	10	10	—	9	5	—	10	10	—	10	5	—	10	10	—	8	3	—	10
9	—	2	9	—	5	9	—	7	9	—	5	8	—	6	9	—	4	9	—	2
9	—	8	9	—	9	9	—	4	6	—	10	9	—	6	9	—	9	9	—	8
10	—	10	8	—	10	10	—	10	7	—	10	10	—	10	8	—	10	10	—	10
10	—	10	5	—	10	10	—	10	3	—	10	10	—	10	2	—	10	10	—	10
10	—	10	9	—	10	10	—	10	10	—	10	10	—	10	9	—	10	10	—	10
10	—	10	10	—	9	9	—	10	10	—	10	8	—	10	10	—	9	9	—	10
	9			9			10			10			9			9			1	

of topcoat on
nel

12/ Impossible to determine chalking on San Diego panels because of extremely high tide at time of inspection
13/ A few pin holes only
14/ Antifouling and topcoat lost exposing primer
15/ F = few
16/ Loss of topcoat exposing gray seal coat
17/ System No. 11 failed
18/ D = dense
19/ Delamination of prime zinc silicate coating

B

PANELS AT PORT HUENEME AND SAN DIEGO

		4						5						6					
SD		PH			SD			PH			SD			PH			SD		
T	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S
9	9	10	10	10	9	10	9	9	10	10	9	9	9	10	10	10	10	10	9
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	4	10	10	10	10	10	10	10	10	10	10
N	N	N	N	N	N	N	N	N	F[15]	N	N	N	N	N	N	N	N	N	N
1[14]	1[14]	10	10	10	10	10	10	10	1[16]	3[16]	10	0[16]	0[16]	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
9[10]	9[10]	10	10	10	9[10]	10	9[10]	9[10]	10	10	9[10]	9[10]	9[10]	10	10	10	10	10	9[10]
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
L	M	—	H	M	—	M	M	—	H	M	—	L	H	—	M	M	—	M	H
1	2	—	2	1	—	2	1	—	1	1	—	1	1	—	1	1	—	2	1
8	9	—	9	9	—	8	9	—	7	8	—	7	9	—	9	9	—	9	9
2	3	—	2	1	—	2	2	—	2	2	—	3	2	—	1	2	—	2	1
9	5	—	10	10	—	10	5	—	10	10	—	8	3	—	10	10	—	10	2
5	9	—	7	9	—	5	8	—	6	9	—	4	9	—	2	9	—	5	9
9	9	—	4	6	—	10	9	—	6	9	—	9	9	—	8	9	—	9	9
10	10	—	10	7	—	10	10	—	10	8	—	10	10	—	10	8	—	10	10
10	10	—	10	3	—	10	10	—	10	2	—	10	10	—	10	5	—	10	9
10	10	—	10	10	—	10	10	—	10	9	—	10	10	—	10	9	—	10	10
9	9	—	10	10	—	10	8	—	10	10	—	9	9	—	10	10	—	9	8
9			10			10			9			9			10			10	

12/ impossible to determine chalking on San Diego panels because of extremely high tide at time of inspection
13/ A few pin holes only
14/ Antifouling and topcoat lost exposing primer
15/ F = few
16/ Loss of topcoat exposing gray seal coat
17/ System No. 11 failed and eliminated from test
18/ D = dense
19/ Delamination of primer and topcoat exposing zinc silicate coating

C

Coating System No.	7C						8						9			
Exposure Site	PH			SD			PH			SD			PH			
Panel Zone	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A
General Protection	10	10	10	9	9	9	10	10	10	9	9	9	10	10	10	10
Chalking	—5/	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Checking	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Blistering, size	10	6	6	10	6	6	10	6	8	10	6	6	10	10	10	10
Blistering, frequency	N	M	D18/	N	D	D	N	D	D	N	D	D	N	N	N	N
Flaking	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Cracking	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Undercutting	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Rusting, type I	9	10	10	9	9 10/	9 10/	10	10	10	9	9 10/	9 10/	10	10	10	10
Rusting, type II	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Pitting	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Fouling, amount	—	L	L	—	L	L	—	L	L	—	L	L	—	L	L	—
Fouling, area	—	2	3	—	3	4	—	6	3	—	4	3	—	2	1	—
1. Plant Area	—	2	3	—	6	9	—	7	5	—	8	9	—	2	1	—
2. Animal Area	—	9	9	—	6	5	—	9	8	—	5	4	—	9	10	—
a. Tunicates	—	10	10	—	9	7	—	10	10	—	9	9	—	10	10	—
b. Barnacles	—	9	9	—	6	9	—	9	9	—	5	9	—	9	10	—
c. Mussels	—	10	10	—	10	9	—	10	9	—	9	10	—	10	10	—
d. Bryozoa	—	10	10	—	10	10	—	10	9	—	10	10	—	10	10	—
e. Hydroids	—	10	9	—	10	9	—	10	8	—	9	8	—	10	10	—
f. Tube Worms	—	10	9	—	10	10	—	10	9	—	10	10	—	10	10	—
g. Sponges	—	10	10	-	9	9	—	10	10	—	10	10	—	10	10	—
Overall Rating	9			9			9			9			10			

1/ A = atmospheric zone
2/ T = tidal zone
3/ S = submerged zone
4/ 0 = 100% fouled; 10 = 0% fouled
5/ Impossible to determine chalking on Port Hueneme panels because of contamination at high tide with floating oil
6/ M = medium
7/ Delamination of topcoat on one side of panel
8/ L = light
9/ N = none
10/ Mostly at edge
11/ H = heavy
12/ Im pa of
13/ A
14/ Ar
15/ F
16/ Lo

	8							9						10					
SD		PH			SD			PH			SD			PH			SD		
T	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S
9	9	10	10	10	9	9	9	10	10	10	10	10	10	7	7	7	8	7	7
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
6	6	10	6	8	10	6	6	10	10	10	10	10	10	10	2	2	10	2	2
D	D	N	D	D	N	D	D	N	N	N	N	N	N	N	F	F	N	M	F
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	9	9
9[10/]	9[10/]	10	10	10	9	9[10/]	9[10/]	10	10	10	10	10	10	9	9	9	8	9	9
.0	10	10	10	10	10	10	10	10	10	10	10	10	10	7	8	8	10	7	7
10	10	10	10	10	10	10	10	10	10	10	10	10	10	8	8	8	10	8	8
L	L	—	L	L	—	L	L	—	L	L	—	L	L	—	M	H	—	L	L
3	4	—	6	3	—	4	3	—	2	1	—	5	6	—	3	2	—	2	2
6	9	—	7	5	—	8	9	—	2	1	—	9	9	—	9	9	—	8	9
6	5	—	9	8	—	5	4	—	9	10	—	6	7	—	4	2	—	4	3
9	7	—	10	10	—	9	9	—	10	10	—	9	8	—	10	10	—	9	6
6	9	—	9	9	—	5	9	—	9	10	—	5	9	—	4	9	—	9	9
10	9	—	10	9	—	9	10	—	10	10	—	9	9	—	8	3	—	9	9
10	10	—	10	9	—	10	10	—	10	10	—	10	10	—	10	8	—	10	10
10	9	—	10	8	—	9	8	—	10	10	—	10	9	—	10	7	—	10	10
10	10	—	10	9	—	10	10	—	10	10	—	9	9	—	10	10	—	10	10
9	9	—	10	10	—	10	10	—	10	10	—	8	10	—	10	10	—	9	9
9		9			9			10			10			7			7		

6/ M = medium
7/ Delamination of topcoat on one side of panel
8/ L = light
9/ N = none
10/ Mostly at edge
11/ H = heavy
12/ Impossible to determine chalking on San Diego panels because of extremely high tide at time of inspection
13/ A few pin holes only
14/ Antifouling and topcoat lost exposing primer
15/ F = few
16/ Loss of topcoat exposing gray seal coat

B

	10						12[17]						13					
	PH			SD			PH			SD			PH			SD		
S	A	1	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S
7	7	7	7	8	7	7	10	10	10	10	8	9	10	9	10	9	9	9
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
0	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
2	10	2	2	10	2	2	10	2	2	10	10	2	10	10	10	10	10	10
F	N	F	F	N	M	F	N	F	F	N	N	M	N	N	N	N	N	N
0	10	10	10	10	10	10	10	4[19]	8[19]	10	0[19]	2[19]	10	10	10	10	10	10
0	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
9	10	10	10	10	9	9	10	10	10	10	10	10	10	10	10	10	10	10
9	9	9	9	8	9	9	10	10	10	10	8	9	10	9	10	9	9	9
7	7	8	8	10	7	7	10	10	10	10	10	10	10	10	10	10	10	10
8	8	8	8	10	8	8	10	10	10	10	9	9	10	10	10	10	10	10
—	—	M	H	—	L	L	—	M	H	—	L	M	—	H	M	—	L	M
2	—	3	2	—	2	2	—	3	2	—	4	0	—	2	2	—	2	1
9	—	9	9	—	8	9	—	8	9	—	8	9	—	8	9	—	9	9
3	—	4	2	—	4	3	—	6	3	—	4	2	—	3	4	—	2	3
6	—	10	10	—	9	6	—	10	10	—	10	8	—	10	10	—	9	4
9	—	4	9	—	9	9	—	7	10	—	7	9	—	7	10	—	4	9
9	—	8	3	—	9	9	—	7	5	—	10	9	—	3	4	—	9	9
0	—	10	8	—	10	10	—	10	7	—	10	10	—	10	9	—	10	10
0	—	10	7	—	10	10	—	10	7	—	10	10	—	10	8	—	10	10
0	—	10	10	—	10	10	—	10	9	—	10	10	—	10	9	—	10	10
9	—	10	10	—	9	9	—	10	10	—	10	8	—	10	10	—	9	9
	7			7			9			8			9			9		

to determine chalking on San Diego
ause of extremely high tide at time
on
holes only
g and topcoat lost exposing primer

coat exposing gray seal coat

17/ System No. 11 failed and eliminated from test
18/ D = dense
19/ Delamination of primer and topcoat exposing zinc silicate coating

C

Unclassified
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13. ABSTRACT

This is the eighth of a series of reports on the protection of mooring buoys. Thirteen test buoys were given their seventh rating for extent of coating deterioration, corrosion of steel, and fouling. Two other buoys had previously been removed from testing because of advanced deterioration. The coating systems on three of the buoys were in good condition while those on 10 others showed varying degrees of moderate deterioration. Two sets of 13 panels each, coated with the different systems used on the buoys, were given their sixth rating inspection after 3 years of exposure. One set was exposed in San Diego Bay and the other in Port Hueneme Harbor. The condition of the coatings on both sets of panels was generally better than that of the buoy coatings, but there was a general correlation between the conditions of the two test groups. On buoys coated with antifouling paints, no detectable antifouling protection remained after 25 months, but on both sets of test panels, two antifouling paints were still appreciably reducing fouling after 3 years.

Three of the buoys were cathodically protected with zinc anodes. The level of protection was high enough to mitigate rusting in the underwater portions of these buoys.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Mooring						
Protection						
Coating						
Cathodic protection						
Rusting						
Deterioration						
Corrosion						
Fouling						
Antifouling						
Chalking						
Blistering						
Flaking						
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